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Vulnerability Assessment Using Fragility Curves

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Abstract

The use of fragility curves for the assessment of seismic losses is in increasing demand, both for pre-earthquake disaster planning as well as post-earthquake recovery and retrofitting programs. Fragility curves; important components of accurate risk assessment are functions that describe the probability of failure, conditioned on the full range of loads to which a system might be exposed. In general fragility curves provide estimates for the probabilities of a structure reaching/ exceeding limiting deformation at given levels of ground shaking or it is a plot of the computed probability (deflection) Vs. Ground motion parameter. The scope of the proposed research is to develop fragility curves as a tool to develop suitable measures that can help in estimating the losses for the structures, similar to the case study building and thus to develop the same as an important tool in earthquake engineering mainly for urban risk reduction.

The objective of the proposed study is the reliability assessment of the case study building to earthquake loadings through the development of fragility curves. The vulnerability of the structure is expressed with the development of fragility curves, which provides the probability of exceeding a prescribed level of damage for a wide range of ground motion intensities. Primary task is to identify a case study structure for which fragility curves are not developed yet and which could effectively represent the structural viability of present and future buildings. It is based on a concept that similar type of structures (structural typology) will have same probability of a given damage state for given earthquake intensity. Hence effective methods to develop fragility curves for representative buildings are very vital in earthquake engineering. We propose to develop fragility curves for a building with flat-slabs and shear wall system which effectively represents recent high rise buildings particularly in GCC countries.

Keywords: Earthquake Engineering, Reliability Analysis, Earthquake Engineering, Fragility Curves, Shear Wall System, Flat Slab Structures.

INTRODUCTION

BACKGROUND

Earth and its environment have become increasingly vulnerable to natural hazards. This being the situation, it is quite important to adopt proper assessment methods, planning and design techniques to prevent the effect of natural hazards like earthquake, wind etc. into extreme disasters. Lack of proper planning and ill-engineered construction are the main causes which increases the risk of natural hazards. In this scenario, vulnerability assessments play a major role in the design, construction and maintenance of structures. Earthquake vulnerability studies/assessment, when properly integrated with engineering measures helps to minimize building/infrastructure damages.

PERFORMANCE BASED ENGINEERING

Performance-based design is a more general design philosophy in which the design criteria are expressed in terms of achieving stated performance objectives when the structure is subjected to stated levels of seismic hazard. The performance targets may be a level of stress not to be exceeded, a load, a displacement, a limit state or a target damage state. Performance based engineering implies a shift away from the dependence of empirical and experience based conventions and towards a design and assessment process more firmly rooted in the realistic prediction of structural behavior under a realistic description of spectrum of loading environment that the structure will experience in future. It allows for selection of a specific performance objective based on various parameters, including the owner's requirements, the functional utility of the structure, the seismic risk and potential economic losses. In spite of these advances, many structures in the GCC countries and around the world were not designed for any level of seismic resistance.

EARTHQUAKE VULNERABILITY ANALYSIS

Another important field of study in earthquake engineering is vulnerability analysis. It is a relatively new research area which needs more input from the researchers. Initiatives such as Hazard United States (HAZUS) have made a substantial start on assessment of vulnerability, using the predicted ground-motion spectrum to estimate the amount of damage that is likely to be inflicted on buildings of known design in a given earthquake scenario. While hazard assessment combines source and attenuation modelling, vulnerability analysis goes one step further, to estimate likely losses to structures by modelling their vulnerability. This results in probabilistic estimates of losses for specific portfolios of assets. Seismology has traditionally been close to the engineering profession, and this has resulted in the development of procedures for earthquake hazard assessment that are useful for engineering design. The advantage of vulnerability assessment is that it can be accurately used to predict damages/losses to buildings owing to earthquake and so can be effectively linked to risk management sectors.

FRAGILITY CURVES

Fragility curves are functions that describe the probability of failure, conditioned on the full range of loads to which a system might be exposed. In general fragility curves provide estimates for the probabilities of a population of structures reaching/ exceeding limiting deformation at given levels of ground shaking or it can be defined as a plot of the computed probability (deflection) Vs. Ground motion parameter. The data derived from fragility curves can be used to analyse, evaluate and improve the seismic performance of both non-structural and structural elements.

Fragility curve is an effective tool for vulnerability assessment of structural systems. The fragility curve, which is developed from the behaviour model of structure, capacity and a suite of ground motions, is a graphical representation of the seismic vulnerability of a structure.

LITERATURE REVIEW

A number of studies have been carried out by eminent researchers and engineers in the field of performance based design and vulnerability analysis using fragility curves. This paper analyzed more relevant and recent research papers related to the field. Review of previous researches done in the area is made.

GENERAL

Park et al. (1985), proposed a method for evaluating structural damage of reinforced concrete buildings under random earthquake excitations. Extensive damage analysis of SDF systems and typical MDF reinforced concrete buildings were performed. On the basis of these results, a simple relationship between the destructiveness of the ground motions, expressed in terms of the “characteristic intensity,” and the structural damage, expressed in terms of the “damage index,” is established. Reinforced concrete buildings that were damaged during past earthquakes were used to calibrate the proposed damage measure; on this basis, practical limits of structural damage are defined [1].

Shome and Cornell (1999), in their conference paper presented the criteria for selection of earthquake. Also suggested different techniques for normalizing or scaling the accelerograms data for nonlinear time history analysis. Scaling can be done based on PGA or based on 1st mode pseudo spectral acceleration for damping equal to 5% and it was concluded that the latter is an efficient choice for the medium-rise structures since it provides a proper estimate of seismic demand and capacity of the building, and minimizes the scatter in the results. Minimum number of earthquake required to carry out nonlinear time history analysis affects the stability capacity estimates. These ideas were clearly explained in this paper. Recorded motions are selected from a bin of recorded motions such as the Pacific Earthquake Engineering Research center (PEER NGA database), Consortium of organization for Strong Motion Observation System (COSMOS) or K-NET [2].

Haider et al. (2006), studied about the slender free-standing objects in a building that could be excited into rigorous rocking and/or sliding motion in an earthquake. Some objects might experience overturning and hence damage when impacting on the floor. Objects which do not overturn might still experience significant damage depending on the severity and nature of the collision with the neighboring objects and with the floor when excited into motion. This paper presents fragility curves which define the probability of overturning of objects for given object dimensions, dynamic characteristics of the building and location of the object within the building. A method for calculating the level of shock experienced by the object on pounding with the floor is also presented [3].

Nimry et al. (2015), proposed an indexing method for rapid evaluation of the seismic vulnerability of infilled RC frame buildings in Jordan. The method aims at identifying low and medium rise residential buildings as safe or in need of further detailed evaluation. Following a rapid visual screening, the building is assigned a Basic Capacity Index (BCI); five performance modifiers are identified and multiplied by the BCI to arrive at the Capacity Index (CI) of the building. A Capacity Index lower than a limit CI value indicates that the screened building could experience moderate earthquake damage whereas a higher value implies that minor damage, if any, would take place. Effects of seismicity, local site conditions, horizontal irregularities (setbacks and re-entrant corners), vertical irregularities (soft story at ground floor level) and overhangs on the seismic performance of local buildings were examined. Assessment forms were designed and used to evaluate and rank 112 sample buildings. About 40% of the surveyed buildings were found to be in need of detailed evaluation to better define their seismic vulnerabilities [4].

Hadi et al. (2016), selected three steel moment frame structures with four, seven, and twelve stories, all of which have similar floor plans and are designed based on the old seismic design code (UBC 1997 code), which is vulnerable in accordance with FEMA 356 code. For seismic improvement Concentrically

Braced Frame (CBF), Buckling Restrained Brace (BRB), and shear wall have been used. The seismic performance level of the primary structure and improved structures were compared by means of seismic fragility curve. Earthquake intensity index is "PGA". Finally, by selecting an appropriate damage index, fragility curves of the original structure as well as the improved structures were presented and compared with a normal log distribution, the results of which was analysed [5].

FRAGILITY CURVES

Dumova-Jovanoska (2000), developed fragility curves for two RC structures (6- story and 16-story frame structures) in Skopje, Macedonia using 240 synthetic ground motion data for this region. The fragility curves were developed using discrete damage states from the damage index defined (Park et al., 1985) [1]. Fragility Curves were developed using discrete damage states from defined damage index. From the studies probability of about 50% were identified that no damage shall occur under an earthquake of designed intensity. Earthquake intensity – damage relations compared with previous studies showed consistent results. Predicted damage for structures fully compliant with codes was lower than structures with lower seismic resistance [6].

Shinozuka et al. (2000), developed empirical fragility curves for the Hanshin Expressway Public Corporations' (HEPC's) bridges for the 1995 Kobe earthquake. In addition, analytical fragility curves were obtained for bridges in Memphis, Tennessee and these fragility curves were estimated by statistical procedures [7].

Reinhorn et al. (2002), explained a method for developing global seismic fragility of a RC structure with shear walls by a simplified approach in which fragility is evaluated from the spectral capacity curve and the seismic demand spectrum were introduced. The investigation showed that the inelastic response was influenced by structural parameters such as yield strength, damping ratio and post-yielding stiffness ratio. In addition, they investigated the fragility of structure and structural parameters including strength, stiffness and damping [8].

Shama et al., (2002) conducted seismic vulnerability analysis for bridges supported by steel pile bents. They developed fragility curves for the original and retrofitted bridge probabilistically based on the uncertainties in demand and capacity. This curve showed that the retrofitting was effective for this bridge type [9].

Tantala et al., (2002) developed vulnerability relationships for a specific class of tall buildings. Prior to this work, such relationships had only been appropriately developed for buildings below 10 stories. The ground motion was simulated as a stochastic process with a prescribed power spectrum, marginal probability distribution function and duration. These ground motions were used with a nonlinear finite element model with uncertain material properties to generate, the statistics of the response of a tall, reinforced concrete moment resisting frame building. It is been concluded that fragility curves can be used for emergency management and for estimating the overall loss after an earthquake. It is observed from the studies that longer the duration, higher the probability of exceeding certain damage level for a given PGA. Accurate forecasts are possible taking into account the tall building behaviour and duration effects [10].

Gardoni et al., (2002-2003) developed multivariate probabilistic capacity and demand models for RC bridges that account for the prevailing aleatory and epistemic uncertainties. A Bayesian approach was used to account for different types and sources of information including lower and upper bound data. The fragility of structural components and systems were estimated. Point and predictive fragilities were revealed as well as confidence intervals that reflect the influence of the epistemic uncertainties [11].

Cornell et al. (2002) developed a probabilistic framework for seismic design and assessment of steel moment frame building structures for the SAC FEMA guidelines. Demand and capacity were expressed in terms of the maximum interstory drift ratio with a nonlinear dynamic relationship. The probability assessment framework was developed with the assumption of distribution on parameters in a closed form. In addition, probabilistic models for structural demand and capacity were used to include uncertainties [12].

According to Wen et al., (2004) a fragility curve is defined as "the probability of entering a specified limit state conditioned on the occurrence of a specific hazard, among the spectrum of hazards." He defines a vulnerability function as "the probability of incurring losses equal to (or greater than) a specified monetary unit, conditioned on the occurrence of an earthquake with a specified intensity." The vulnerability of a structure is determined by a probabilistic relation between the predicted limit state and some measure of the earthquake demand, such as spectral acceleration (Sa), peak ground acceleration (PGA) probability of recurrence, or a specified ground motion magnitude [13].

Erberic and Elnashai, (2004) conducted a study on flat slab structures. The main focus was on the derivation of fragility curves for medium rise flat slab buildings with masonry infill walls. The case study building was modelled as a 2-D plane frame with lumped masses in ZEUS-NL, a software program used for inelastic analysis of flat slab structures. Spectral displacement was used as the hazard parameter for the development of the curves. The developed curves were compared with RC moment resisting frames [14].

Bekir Ozer (2006) assessed structural vulnerability of reinforced concrete frame structures by considering the country–specific characteristics to manage the earthquake risk and to develop strategies for disaster mitigation. Low–rise and mid–rise reinforced concrete structures, which constitute approximately 75% of the total building stock in Turkey, are focused in this fragility–based assessment. The seismic design of 3, 5, 7 and 9–story reinforced concrete frame structures are carried out according to the current earthquake codes and two dimensional analytical models are formed accordingly. The uncertainty in material variability is taken into account in the formation of structural simulations. The demand statistics in terms of maximum interstory drift ratio are obtained for different sets of ground motion records. The capacity is determined in terms of limit states and the corresponding fragility curves are obtained from the probability of exceeding each limit state for different levels of ground shaking. The results are promising in the sense that the inherent structural deficiencies are reflected in the final fragility functions. Consequently, this study provides a reliable fragility–based database for earthquake damage and loss estimation of reinforced concrete building stock in urban areas of Turkey [15].

Performance levels based on additional quantitative limits were also considered. Varying degrees of reduction in the seismic fragility were demonstrated through the use of the three selected retrofit techniques. The fragility curves were compared to those for RC structures derived in other studies and it was found that the results based on this study are comparable.

Mary Beth and Jong Wha Bai, (2007) conducted an assessment of seismic fragility for a reinforced concrete frame structure representative of 1980's construction in central U.S. The performance of the retrofitted structure is presented in terms of fragility relationships that relate the probability of exceeding a performance level to the earthquake intensity. In addition, seismic fragility relationships were developed for the retrofitted structure based on three possible retrofit techniques and several performance levels [16].

Korkmaz (2008) evaluated probabilistic seismic analyses to define the structural seismic behavior. A representative R/C frame structure is taken in to consideration in the analytical part. A comparison is realized with the results of different methodologies as Monte Carlo Simulations and analytical based analysis. The main objective was to evaluate the methodologies for probabilistic seismic assessment in terms of fragility assessment. The probabilistic seismic performance is measured by fragility curves, that is, the probability of system failure as a function of earthquake consequences of system damage and failure, and system probability of failure [17].

Zentner et al., (2011) explained statistical estimation of the parameters of fragility curves and presented results obtained for a reactor coolant system of nuclear power plant. In nuclear engineering practice, fragility curves are often determined by means of margin factors, using the scaling method. This approach allows for determining fragility curves in a very convenient way but makes strong simplifying hypothesis. This is why it can be interesting to directly propagate uncertainties by means of Monte Carlo simulation [18].

Fardis et.al., (2012) constructed fragility curves for a portfolio of prototype regular RC frame and wall-frame buildings designed and detailed to Euro Codes EC2 and EC8. The aim is to use EC8's own seismic performance assessment methods and criteria for existing buildings to evaluate how EC8 achieves its performance goals for new RC buildings. The overall conclusion is that these goals are met in a very consistent and uniform way across all types of buildings considered and their geometric or design parameters, except for RC walls of Ductility Class Medium, which may fail early in shear despite their design against it according to EC8. In fact, these walls do not perform much better than those of braced systems designed to EC2 alone. Another finding is that the slenderness limits and the lateral bracing requirements of EC2 for 2nd-order effects under factored gravity loads place severe restrictions on the size of columns and walls, which, although ignored in ordinary seismic design practice, materially impact the outcome of the design and, to a smaller extent, the seismic fragilities of the building's members. Another finding is that the reduction in fragility from higher design peak ground accelerations is disproportionately low. Even buildings designed for gravity loads only, but in full accordance to EC2, possess substantial seismic resistance [19].

Pierluigi Olmatia and Francesco Petrini (2014) in their paper presents a probabilistic method to support the design of cladding wall systems subjected to blast loads. The proposed method is based on the broadly adopted fragility analysis method (conditional approach), widely used in Performance-Based Design procedures for structures subjected to natural hazards like earthquake and wind. The cladding wall system under investigation is composed of non-load bearing precast concrete wall panels. From the blast design point of view, these wall panels must protect people and equipment from external detonations. The aim of the research was to compute both the fragility curves and the limit states exceedance probability of a typical precast concrete cladding wall panel considering the detonations of vehicle borne improvised explosive devices. Moreover, the limit states exceedance probability of the cladding wall panel is estimated by Monte Carlo simulation (unconditional approach) in order to validate the proposed fragility curves [20].

Pratibha et al., (2014) explained in their paper a methodology based on pushover analysis for fragility estimates of RC building using probabilistic approach. It is observed that the analytical base shear values for the derived values of strength based on factor of safety into consideration were almost equal to that of experimental pushover values. Also an attempt has been made to obtain fragility estimates for the reference building assumed to be located in Zone IV and damage states were also established and reported [21].

Bakshi and Ansari (2014) in their study concentrated on the probabilistic risk assessment of reinforced concrete tall buildings subjected to ground motion excitation. This evaluation is done by developing fragility curves. These fragility curves provide the probability of exceeding the multiple damage states for a given intensity of ground motion excitation. This study includes comparison between fragility curves of fixed base buildings and the ones derived from models considering the Soil Structure Interaction effects to indicate the efficacy. The structural uncertainties are taken into account by generating and modelling random values of material properties using Monte Carlo simulation method [22].

Thai et al., (2014) in their paper represents a simplified seismic fragility analysis approach of the underground tunnel structure in consideration of the soil-structure interaction effect. Soil Structure Interaction effect founds to be essential in the estimation of dynamic analysis of underground structures like tunnels and thus needs to be considered. The ground response acceleration method for buried structures known to be a very efficient quasi-static method that can consider Soil Structure Interaction effect is used in the proposed approach to evaluate seismic structural responses without sacrificing much accuracy. Seismic fragility curves are then developed by applying the maximum likelihood estimates to responses of a large set of artificial ground motion time histories generated for multiple different levels of earthquake intensity [23].

Aiswarya et al., (2014) conducted study on the flat slab system subjected to different ground motions and developed the fragility curve based on the pre-defined damage state. Twenty five artificial ground motions were selected from the PEER ground motion database and were applied to these sample building. Fragility curves were developed by considering the damage states from FEMA 356(2000).From this they concluded that flat slab systems are more vulnerable to seismic hazard because of their insufficient lateral resistance and undesired performance at high levels of seismic demand. Based on this they proposed the retrofitting technique like inclusion of shear wall. The fragility curve developed for retrofitted building was then compared with that of the unretrofitted building and concluded that the addition of shear wall has improved the seismic response of the building [24].

Marco Vona (2014) presented a procedure to develop analytical fragility curves for Moment Resisting Frame Reinforced Concrete buildings. The design of the selected building typologies was performed according to the codes at the time of construction using force-based methods and the state of the practice at the time of construction. A total of 216 building classes were defined, considering different ages, number of storeys, infill panels, plan dimensions, beam stiffness, and concrete strength. The investigated buildings can be considered low-engineered buildings, using no seismic codes or old seismic codes. The seismic capacity of the selected models representing the existing RC buildings has been evaluated through non-linear dynamic simulations. A new relationship among structural performance, damage levels and inter-storey drift ratios for each studied type is introduced, which is calibrated using the damage levels described in EMS98. It is important to highlight that in this study, different thresholds of IDR have been associated with different typologies, considering their different ductility member levels after their different structural responses [25].

Suraj V. Borele (2015).This paper dictates the methodology for the generation of fragility curve which is the graphical representation of the seismic risk of a structure. In this study the fragility curves were developed based on the, guidelines given by HAZUS technical manual. Two and four storey RC frame building was selected for the case study and their seismic behaviour with and without infill was taken into consideration. The infill wall was modeled as an equivalent diagonal strut and the width of the struts for each infill panel is evaluated by using the guidelines given in FEMA 356. The RC buildings were modelled and analyzed using SAP2000 v14 and the design was based on IS 456:2000 and IS 1893(Part 1):2002. Static Non-linear analysis or Pushover analysis of the building models was carried out capacity curves were developed from this. The results of the capacity curve were used to plot the fragility curve. The fragility curves developed from this study were used to compare the seismic performance of the building models [26].

Vahid Rahimi (2015) developed fragility curves via Hazus methodology for estimation of seismic risk assessment in the city of Semnan, Iran. For determination of structural fragility curves, required parameters obtained from study ward and some of governmental reports Obtained fragility curves shows model building types are vulnerable to slight damage and least vulnerable to complete damage in each of design level code in study area of Semnan. Logic results show Hazus methodology can be utilized for seismic risk assessment [27].

Siti & Fadzli (2015) presented a study on development of fragility curve for Malaysian low- and mid-rise buildings that are reinforced concrete and steel moment–resisting frames. Two prototype models, which include three- and six-story frame structures with different types of material, were designed based on Eurocodes. Incremental dynamic analysis (IDA) was conducted under seven sets of ground motion records, and scaling peak ground acceleration increased every 0.05 g until it achieved 0.6 g. The software SAP2000 was used to perform IDA. Five levels of performance based seismic designs, namely, operational phase, immediate occupancy, damage control, life safety, and collapse prevention, were considered to assess structural performance. Seismic fragility curves were developed for structural models with different types of material and height [28].

Vazurkar & Chaudhari, (2016) detailed the vulnerability assessment of reinforced concrete buildings using fragility curves. Fragility curve describes the probability of damage being exceeded a particular damage state. In this study the fragility curves were developed based on the, guidelines given by HAZUS technical manual. The RC buildings were modelled and analyzed using SAP2000 v14. Non - linear static analysis procedure is used for the analysis of RC buildings. The pushover analysis was carried out as per the guidelines given in ATC40. Pushover analysis was conducted and the capacity curve was plotted. Results obtained from pushover analysis are used for plotting the fragility curves. For plotting the Fragility Curves Spectral Displacement were considered as the ground motion parameter. The damage states were described as per the HAZUS technical manual. Finally, based on the obtained fragility curves the spectral displacement values that satisfy the predefined performance level requirements were estimated. These plotted fragility curves were used to study the seismic performance of building models [29].

CONCLUSIONS

One of the effective ways to lessen the impact of earthquake disaster on buildings/infrastructure is accurate risk assessment and implementation of methods to mitigate the same. Hence damage and loss estimation is a key tool in earthquake disaster management and fragility curves can be used for the purpose.

In the literature survey a series of papers by previous researchers who dealt with fragility curves were analysed. Fragility curves can be used for reliability and vulnerability assessment of buildings. Fragility curves developed for a building can be effectively used as a tool for predicting the damage levels for buildings of similar type.

REFERENCES

[1] Park Y.J, Ang A.H.S and Wen Y.K, *"Seismic damage analysis of reinforced concrete buildings"*, Journal of Structural Engineering ASCE;111(4):740-57

[2] Shome, N., & Cornell, C. A. (1999). *Probabilistic seismic demand analysis of nonlinear structures.* Report No. RMS-35, RMS Program, Stanford University, Stanford

[3] Haider A. Al Abadi, Nelson T.K. Lam & Emad F. Gad. (Nov 2006) *"Seismic fragility curves for damage to building contents",* Earthquake Engineering in Australia, Canberra, 161 Page 24-26

[4] Al-Nimry, H., Resheidat, M. & Qeran, S. Earthq. Eng. Eng. Vib. (2015) 14: 275. doi:10.1007/s11803-015-0023-4

[5] Hadi Faghihmaleki, Hamid Roosta , Ali Hooshmand Aini ,Elmira Khaksar Najafi (2016) *"Using Fragility Curves for the Evaluation of Seismic Improvement of Steel Moment Frames",* Afyon Kocatepe University Journal of Science and Engineering AKU J.Sci.Eng.16(2016)025601(323- 337)

[6] Dumova-Jovanoska, E. *"Fragility Curves for Reinforced Concrete Structures in Skopje (Macedonia) Region"* (2000). *Soil Dynamics and Earthquake Engineering*, 19, 455-466.

[7] Shinozuka, M., Feng, M. Q., Lee, J. and Naganuma, T. *"Statistical Analysis of Fragility Curve" (2000)*. Journal of Engineering Mechanics, 126(12), 1224-31.

[8] Reinhorn, A.M., Barron-Corverra, R. and Ayala, A.G. *"Global Spectral Evaluation of Seismic Fragility of Structures,"* (2002). Proc., 7th U.S. National Conference on Earthquake Engineering, Boston.

[9] Shama, A.A., Mander, J.B. and Chen, S.S. *"Seismic Investigation of Steel Pile Bents: II. Retrofit and Vulnerability Analysis,"* (2002). *Earthquake Spectra*, 18, (1), 143-160.

[10] Michael, Tantala, W. and George, Deodatis. *"Development of Seismic Fragility Curves for Tall Buildings." (2002).* 15th ASCE Engineering Mechanics Conference.

[11] Gardoni, P., Kiureghian, A.D., and Mosalam, K.M. *"Probabilistic Capacity Models and Fragility Estimates for Reinforced Concrete Columns based on Experimental Observations"* (2002). Journal of Structural Engineering, 128, (10), 1024-1038.

[12] Cornell, C.A., Jalayer, F., Hamburger, R.O., and Foutch, D.A. *"Probabilistic Basis for 2000 SAC Federal Emergency Management Agency Steel Moment Frame Guidelines"* (2002). Journal of Structural Engineering, 128, (4), 526-533.

[13] Wen, Y. K., Ellingwood, B. R., Bracci, J. *"Vulnerability Function Framework for Consequence-based Engineering."* (2004). *MAE Center, Project DS-4 Report.*

[14] Altug, Erberic, M. and Amr, Elnashai, S. *"Fragility Analysis of Flat Slab Structures*" (2004). Engineering Structures, Vol 26, 937-948.

[15] Ay, Bekir Özer Thesis for M.S., Department of Civil Engineering METU, CE, August 2006

[16] Mary, Beth, Hueste, D. and Jong, Wha, Bai. (2007*). "Seismic Retrofit of a Reinforced Concrete Flat Slab Structure: Part II- Seismic Fragility Analysis"* Engineering Structures, 29, 1178-1188.

[17] Korkmaz K.A, (2008) *"Evaluation of seismic fragility analyses",* The 14th World Conference on Earthquake Engineering October 12-17, 2008, Beijing, China

[18] I. Zentner , N. Humbert , S. Ravet & E. Viallet (2011): *Numerical methods for seismic fragility analysis of structures and components in nuclear industry - Application to a reactor coolant system*, Georisk: Assessment and Management of Risk for Engineered Systems and Geohazards, 5:2, 99-109

[19] Fardis, M.N., Papailia, A. & Tsionis, G. Bull Earthquake Eng (2012) 10: 1767. doi:10.1007/s10518-012-9379-2

[20] P Olmati, F Petrini, K Gkoumas – "*Fragility analysis for the Performance-Based Design of cladding wall panels subjected to blast load* ", Engineering Structures, 2014

[21] Prathibha S. Shetty, Swathi T. Shetty, Ramakrishna Hegade, C.M. Ravi Kumar , K.S. Babu Narayan & D. Venkat Redd *Fragility Estimates of Rc Building Using Etabs*, Global Journal of Earth Science and Engineering, 2014, 1, 49-56 49

[22] A. Bakhshi & M. Ansari Proceedings of the 9th International Conference on Structural Dynamics, "*Development of seismic fragility curves for reinforced concrete tall building"* EURODYN 2014 Porto, Portugal, 30 June - 2 July 2014 A. Cunha, E. Caetano, P. Ribeiro, G. Müller (eds.) ISSN: 2311-9020; ISBN: 978-972-752-165-4

[23] Le, T.S., Huh, J. and Park, J.-H. (2014) *"Earthquake Fragility Assessment of the Underground Tunnel Using an Efficient SSI Analysis Approach"*. Journal of Applied Mathematics and Physics, 2, 1073-1078.

[24] S Aiswarya, Nandita Mohan, *"Vulnerability analysis by the development of fragility curves,"* IOSR Journal of Mechanical and Civil Engineering (IOSR - JMCE), pp. 33-40, May 2014

[25] Vona, M. (2014) "*Fragility Curves of Existing Rc Buildings Based on Specific Structural Performance Levels"*. Open Journal of Civil Engineering, 4, 120-134.

[26] Suraj V. Borele, "*Damage assessment of structural system using fragility curves"* Journal of Civil

Engineering and Environmental Technology, vol 2, pp. 72-76, June 2015

[27] Vahid Rahimi, Mohammad Iman Khodakarami, Reza Vahdani, *Determination of Structural Fragility Curves of Buildings with Hazus methodology for Seismic Risk Assessment in the city of Semnan, Iran*. 10th International Congress on Civil Engineering 5-7 May 2015 University of Tabriz, Tabriz, Iran,

[28] Siti Nur Aqilah Saruddina , Fadzli Mohamed Nazria, "*Fragility curves for low- and mid-rise buildings in Malaysia"*The 5th International Conference of Euro Asia Civil Engineering Forum (EACEF-5)

[29] Vazurkar U. Y and Chaudhari, D. J, *"Development of Fragility Curves for RC Buildings"* International Journal of Engineering Research, vol 5, pp.591-594, February 2016

[30] Bradley, B. A., Dhakal, R. P., Mander, J. B. and Macrae, G. A. (2007). *"Improved Hazard Model For Performance Based Earthquake Engineering."* Newzeland Conference on Earthquake Engineering.